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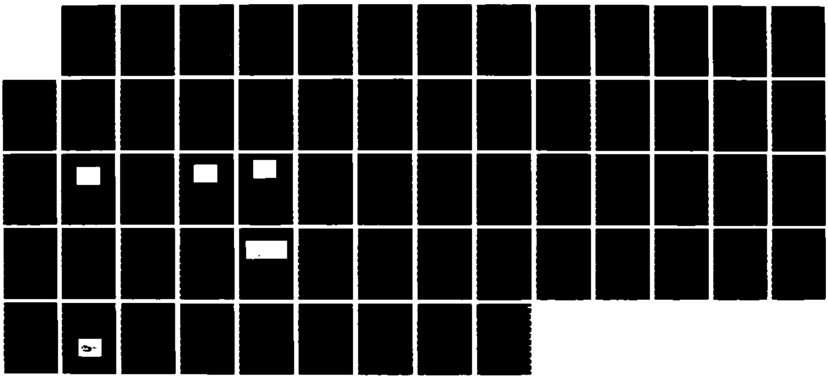

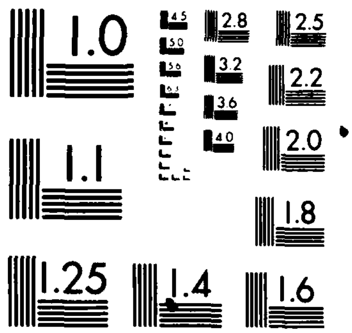

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MEASUREMENT AND ANALYSIS
OF THE MEMORY CAPABILITIES
OF A CONDUCTING PRIZ

THESIS

Mark E. Nilius
Major, USAF

AFIT/GEO/ENP/85D-3

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OF A CONDUCTING PRIZ

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

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Master of Science in Electrical Engineering

Mark E. Nilius, M.S.

Major, USAF

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Preface

This work is a continuation of a research project initiated in 1982, and sponsored since 1983 by FTD. This study is a follow-on to a previous AFIT thesis. That thesis centered on the construction and qualitative analysis of a current conducting PRIZ exhibiting dynamic image selection. Dr. Theodore Luke, my thesis advisor, suggested a quantitative investigation into the operational characteristics of the PRIZ. Specifically, the storage or memory capabilities of the device were chosen for investigation. This investigation required the construction of a conducting PRIZ exhibiting dynamic selection, a task which had only been accomplished once outside the Soviet Union, and that at AFIT in 1984.

I would like to thank Dr. Luke for the proposal and for his valuable assistance throughout the project. Mr. Ron Gabriel, and Mr. George Gergal provided technical guidance in all areas of my experimentation. Dr. Darrel G. Hopper of FTD arranged equipment funding in support of this research.

Finally, a special thanks to my wife, Susan, and daughters, Trina and Traci, for their love and support during my AFIT tour. My loving family has always been my key to success.

Mark E. Nilius

TABLE OF CONTENTS

List of Figures

Abstract

The memory (storage) capabilities of a conducting PRIZ spatial light modulator were quantified. Analysis shows a relationship between the storage capabilities of the device and operation of the device as a dynamic image selector. Conditions for optimizing these capabilities are established. This is the first time quantified values have been presented concerning either the storage or dynamic imaging capabilities.

The AFIT PRIZ's exhibited memory capability for up to one hour. The operating conditions that affect the device's ability to store information are: read beam on/off status, external electric field on/off status, and the write beam energy density.

Two other effects were observed and reported. One is an effect referred to as background glow. This is the first report of the glow. The second is reintensification of the output image.

Construction of operational American devices exhibiting dynamic image selection was accomplished for only the second time. Fabrication of these devices was accomplished using the technique developed by Shields (20:62) in his construction of the first non-Soviet PRIZ device exhibiting dynamic image selection.

MEASUREMENT AND ANALYSIS OF THE MEMORY CAPABILITIES OF A CONDUCTING PRIZ

I. Introduction

Optical signal processing, optical computing, and image pattern recognition require real-time reusable devices on which the input data to be processed can be recorded for subsequent optical manipulation (6:3846). The PRIZ, a Russian acronym for one of their spatial light modulators, may fulfill these requirements.

The Soviet built PRIZ devices have been tested in the United States (5:4215, 4:3090). The tests were conducted at Carnegie Mellon University with Dr. David Casasent as the chief American evaluator. Two different PRIZ devices have been described by the Soviets. One device consists of a photorefractive crystal, such as $Bi_{12}SiO_{20}$ (BSO), sandwiched between two deposited dielectric layers. Transparent conducting electrodes are then deposited over the dielectric layers. This device shall be referred to as the "standard" PRIZ. The second device does not utilize the dielectric layers. Instead the transparent conducting electrodes are placed in direct contact with the photorefractive crystal. The device with this type of construction will be called the "conducting" PRIZ. Figure 1

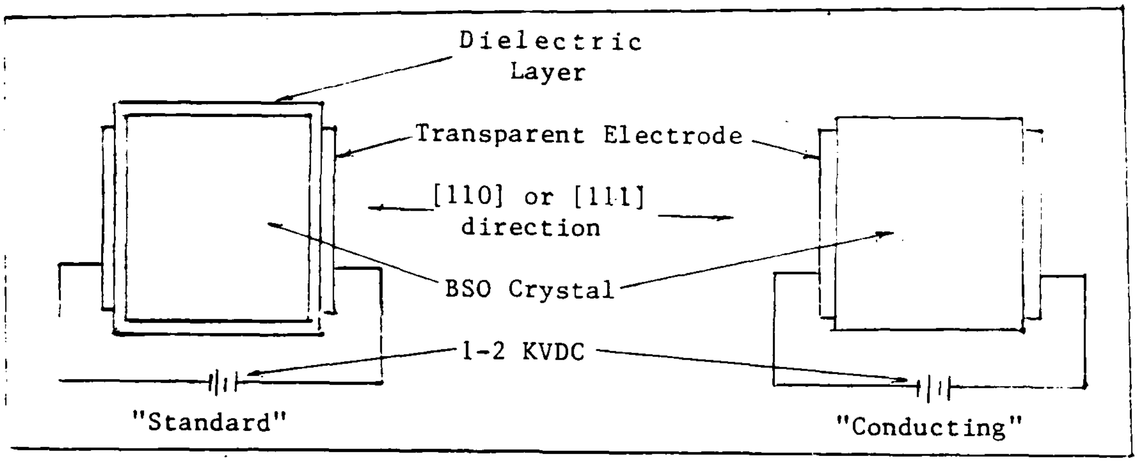


Fig. 1. PRIZ Configurations

illustrates the two structures of the PRIZ. Casasent states in his report (5:4216) that "dielectric layers were used on all devices" tested at Carnegie-Mellon thus implying only the "standard" PRIZ has been tested in the U.S., however, he later reports on experimental results obtained from the "conducting" version (6:3851). The latter is probably correct. It was the "conducting" (no dielectric layers) version of the PRIZ that was studied during this research (see Appendix for specific construction of the devices).

Another type of spatial light modulator is the PROM (Pockels readout optical modulator). The PROM's construction is very similar to that of the standard PRIZ; both are constructed using dielectric layers between the crystal and the transparent electrodes. The PROM, however, uses a (100) crystal cut whereas the PRIZ uses a (111) or (110) cut. Both versions of the PRIZ use the transverse electrooptic effect to spatially modulate a readout beam whereas the PROM uses the longitudinal electrooptic effect.

The Soviet devices tested by Casasent (5:4216) consisted of one PROM and four standard PRIZ spatial light modulators. Additionally a comparison of an American made PROM was included in Casasent's study (5:4220). Analyses such as these clearly show that the PRIZ has from 10 to 100 times more useable light than does the PROM (5:4220). The PRIZ also demonstrated several unique operational characteristics. These include: dynamic image selection (the ability of the device to distinguish between moving and non-moving images); suppression of the d.c. component; and directional filtering. It should be noted that in order for dynamic image selection to manifest itself the device is operated with a fixed voltage across the electrodes (5:4220).

Several reports have been published, in both American and Soviet literature, concerning the operational characteristics of the PROM (5:4215), standard PRIZ (4:3090), and conducting PRIZ (6:3851). Although the storage capabilities of the PROM and standard PRIZ are clearly reported by several sources, only Shields (20:49) discusses the memory characteristics of the conducting PRIZ. It appeared, after surveying the literature, that the memory capabilities must be related to the dynamic imaging mode of operation. Therefore, the storage time of the conducting PRIZ was characterized to establish the relationship between the long term storage capabilities of the device and dynamic image selection.

Sequence of Presentation

The operation of the conducting PRIZ is presented in Chapter II. The material covered includes: The current state of the art; the concept of operation used in this work; and some possible applications.

Chapter III contains the statement of the problem examined during this study along with the approach taken to solve the stated problem.

The results of an investigation of the PRIZ's ability to store information (device memory) is described in Chapter IV. An analysis of the results of the experiments performed is presented in Chapter V. Comparison of the Soviet device operational parameters with the experimental results obtained in Chapter IV is also included in Chapter V.

Chapter VI contains information on background glow and reintensification, two other effects observed during this study. The effect of background glow is reported for the first time in this study. Reintensification has been previously reported and is analyzed in light of the information obtained in Chapter IV.

The final chapter consists of the summary, conclusions, and recommendations for further research. Although the memory capabilities of the conducting PRIZ were specifically examined, the data obtained during this research applies to all modes of operation, including: long term storage; dynamic image selection; and the write-read-erase mode of operation. An example is included in the conclusions section that demonstrates this fact.

II. Background

Conducting PRIZ - State of the Art

Several references have been made as to the operational characteristics of the Soviet-made conducting PRIZ devices (16:250,13:163). These references must be carefully reviewed to ensure that the Soviets are describing the conducting and not the standard PRIZ. In some reports it is not possible to make this discrimination. Casasent et.al., on the other hand, have evaluated the Russian made devices and capsulized their operational characteristics. However, neither Casasent nor the Soviets mention device memory when describing the characteristics of the conducting PRIZ.

The operational characteristic of the conducting PRIZ reported in any detail is that of dynamic image selection. Dynamic image selection is a very attractive selling point for this device, because in this mode of operation the device becomes a real-time moving target indicator which could have significant military applications.

Specific details concerning the operation of the conducting PRIZ as a dynamic image selector are limited. Casasent reports that "The response of the device to an 0.5mm wide input line was measured for different velocities (1-40mm/sec) of the input object across the input plane, and it was found (13:165) that the response of the device peaked when the velocity was approximately 7mm/sec" (6:3851). Additionally the ratio of the intensity of the moving spot to the average intensity of the fixed background was measured at the input and output of the system. Results of these measurements showed the intensity of the dynamic part of the output image to be 50 times the average background level in the output (6:3854). Finally, Soviet sources claim that the effect of dynamic selection manifests itself only at fairly high energies of recording light (14:169). Although Soviet sources do not specify the amount of write light energy used to operate the device, Casasent tested the Russian devices using write light energy densities in the range 25-200uJ/cm^2 (5:4217). Assuming this to be the same range used by the Soviets, "fairly high" would equate to energy values greater than approximately 100uJ/cm^2.

To date construction of a non-Soviet made operational conducting PRIZ has been reported only by Shields (20:62-64). The device consisted of a BSO crystal cut from the (111) cut onto which chromium electrodes were evaporated (20:37). Shields qualitatively evaluated the dynamic imaging properties, d.c. suppression capabilities, directional filtering effects, and memory ability of the conducting PRIZ. This was the first report of memory in the conducting version. The operational characteristics required to store an image over long periods of time would not appear to be compatible with the relatively short memory, or storage times, required to operate as a dynamic image selector, yet both characteristics are observed by Shields on the same device (20:37&49).

Operation of the Conducting PRIZ

Based upon experimental data obtained using the PRIZ modulator, Bryksin states (1:193) the image recording takes place through excitation of photocarriers from donors near the valence band by the recording (write) light, the density of charges being proportional to the intensity distribution of this light. The resulting charge distribution creates both longitudinal and transverse electric fields in the crystal leading to the spatial modulation of the birefrigence. In the case of the PRIZ this transverse modulation causes a change in the polarization of the reconstructing polarized light. The amplitude of a coherent read out beam, when read out between crossed polarizers, is now related to the intensity of the original input image (12:644). The device has in effect performed an incoherent (write) to coherent (read) transformation in real-time. Among other things this conversion allows coherent optical processing algorithms to be performed on the image. More importantly, the output image from the PRIZ is a processed version of the input image. This processing may involve, one or more, filtering operations which include spatial band pass, directional, or dynamic imaging. The latter, dynamic imaging, is best exhibited by the conducting PRIZ, since only in this version can scenes be continuously written in without an excessive buildup of internal charge.

Operation of the conducting PRIZ is based on the transverse electrooptic effect. This means that in internal electric field orthogonal to the direction of propagation of the read light in the crystal must be present in order to modulate the read beam (22:261). A write beam of sufficient energy is used to produce the internal electric field required for the modulation to take place. Commonly a laser producing light in the blue-green region of the spectrum is used as the write light; however, the write beam need not be a coherent source. Any source with a sufficiently energetic photon capable of producing photoconduction of the donor electrons in the material can be used.

Applications

The three PRIZ filtering operations previously noted, along with a fourth feature; the ability of the conducting PRIZ to store information for retrieval at a later time (device memory), lead to operational characteristics that are of use in various applications. For example, the PRIZ spatial light modulator could be used in optical pattern recognition, or as an optical signal processing correlator (6:3849). The device's ability to select the dynamic part of an image from a fixed background has several applications, one of which is as a moving target indicator. Finally, based upon current performance, possible applications in optical computing should also be considered.

III. Problem and Approach

Problem

Although the conducting PRIZ has been studied in both the Soviet Union and the United States, reports on the device's ability to store information are limited. Only Shields specifically mentioned the device's ability to store data for up to 20 minutes (20:50). There is currently no quantitative information on the parameters required for the device to store information. The purpose of this study is to quantify the parameters associated with the storage capabilities of the device, and show how they relate to those necessary for operating the device in the dynamic image mode. Specifically, the minimum and maximum storage times will be sought as well as the operational parameters required to obtain these times.

Approach

In order to evaluate the storage capabilities of the conducting PRIZ, several preliminary steps were taken. These included the testing of the chromium deposition technique used by Shields (20:62), the actual fabrication of two conducting PRIZ devices, and a qualitative evaluation of the operation of the device. The fabrication procedures used by Shields (20:64) were followed in constructing the devices used in this study (see Appendix), since his technique has produced the only known non-Soviet operational device.

Once the preliminary steps were accomplished, the problem formulated by this thesis was approached in three phases: evaluation of the optical output, quantification of device memory, and analysis of results.

The first phase, evaluation of the optical output of the device, consisted of a series of experiments to qualitatively test the optical output against varying operational parameters. Specific operating conditions were sought that would allow the device to operate as an effective storage device.

The second phase consisted of a series of experiments designed to quantify the device's ability to store information, (device memory). Specifically the maximum and minimum memory times (storage times) and the parameters needed to realize these times were obtained.

The final phase consists of the analysis of the results obtained in phases one and two. A comparison of these results with the known operating information, specifically when operating in the dynamic image selection mode, was accomplished during this phase.

IV. Device Memory

The specific experimental parameters, experimental procedures, and experimental results are reported in this chapter.

Specific Experimental Parameters

All numerical values of the device memory tested were obtained with the following parameters kept as constant as possible.

1. The energy density of the Helium Neon laser (read beam) on the device was maintained at 100 ± 05uW/cm^2.

2. Unless stated differently, the externally applied electric field was 2000 ± 100 volts. The direction of the applied field was parallel to the direction of the write beam propagation. The front face (large face or the crystal on the write beam input side) contained the negative electrode.

3. Write beam diameter at the PRIZ was 120-150um.

4. A HeCd laser (442nm) was used as the write beam.

5. Either an EG&G 450 photometer/radiometer or a Pacific Precision Instruments photomultiplier tube was used to obtain a time history of the readout of the device. Both devices were sensitive enough to detect the change in the optical output caused by the write beam. However, an area, approximately 15 to 20 times

larger than the output image created by the write beam, was included in the receiving area of these detectors. Therefore, a time history of the background around the actual output image was also integrated into the output of the detectors. Because of this unconventional detection scheme, a device phenomenon, which will be called "background glow" (Chapter VI), was observed and recorded for the first time.

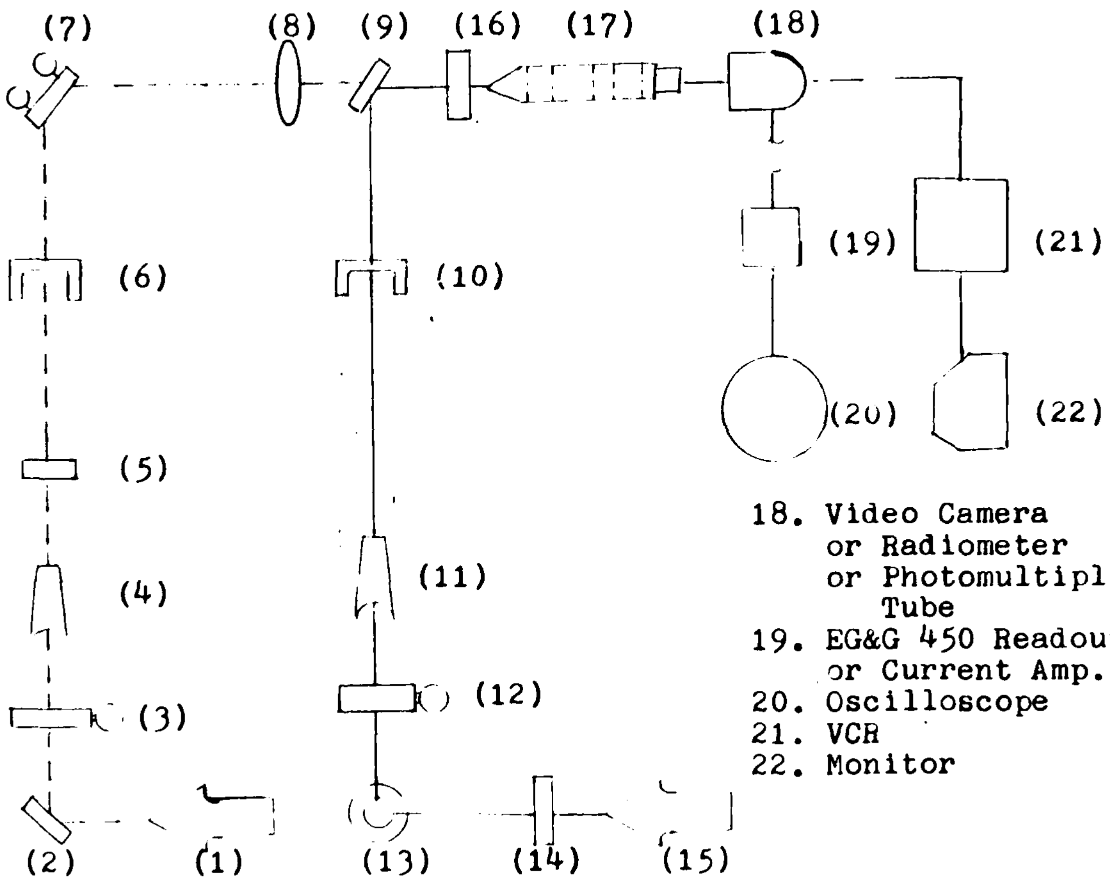
Experimental Procedures

The experimental setup shown in Fig. 2 was used for determining the memory properties of the conducting PRIZ. Readout of the Helium Neon beam was accomplished either visually, using a video camera and TV monitor, or by optical measurements from a photodetector.

The Helium Neon laser was linearly polarized for this experiment since the directional filtering of the output does not affect the memory capabilities of the device. A shutter was placed in the Helium Neon path which allowed the laser to operate continuously without illuminating the device. This eliminated the problems associated with the transients caused when the Helium Neon laser was switched on.

Analysis of the initial qualitative test results served as a

1. HeCd Laser
2. Mirror
3. Shutter
4. Jodon Beam Expander/ Spatial Filter
5. ND #3 Filter
6. Aperture
7. Moveable Mirror
8. 19.5cm lens
9. Beam Splitter
10. Aperture
11. Shutter
12. Jodon Beam Expander/ Spatial Filter
13. Beam Director
14. Linear Polarizer
15. HeNe Laser
16. PRIZ Device
17. Telescope Tube
    a. 5.6X Objective
    b. Analyzer
    c. 6328 Filter
    d. 10X Eyepiece



18. Video Camera or Radiometer or Photomultiplier Tube
19. EG&G 450 Readout or Current Amp.
20. Oscilloscope
21. VCR
22. Monitor

Fig. 2. Experimental Setup

basis for evaluating the device memory. It was clear from the qualitative tests that there was a specific range of write beam energy densities that yielded the slow decaying visual output. Therefore, in order to control and measure the amount of energy placed onto the device by the write beam, a variable aperture was placed in the write beam path. This, along with the shutter, allows control of the specific amount of write beam energy on the device. A fixed pulse width (shutter speed) and varying peak power (aperture) was used for most of this research. During the reintensification analysis both shutter and aperture were varied to obtain the reintensified output.

The specific procedure for device memory determination was as follows: first the external electric field was applied to the device. The Helium Neon beam was blocked by the shutter. Next the device was illuminated with a known write beam energy. Timing was started at this point. Upon reaching a predetermined time, the read beam shutter was opened and reading of the stored information attempted. If memory was evident, the process was repeated and the length of time between writing and reading was increased until a maximum memory, or storage time was established. Throughout this procedure the amount of write beam energy remained constant.

Results

There are three factors that affect the length of time the conducting PRIZ is able to store data. The factors are: the operation of the read beam; the presence of the applied external field; and the write beam energy density placed on the device.

Operation of the read beam is extremely important in realizing the maximum storage capability of the device. The read beam has sufficient energy to photoexcite charge carriers as deep as 1.96ev. Therefore, the uniform illumination of the device by the read beam erases some of the space-charge fields (optical erasure). Erasure of the space-charge fields cause the optical output to decrease. It is possible to completely erase the output image using the read beam. Therefore, a maximum storage time cannot be realized with the read beam on.

A second factor contributing to the memory time of the device is the applied electric field. To show the effect of the electric field on the storage times two extremes were studied; electric field off, and a constant 2000 volts applied. Turning the field off after writing is accomplished, and turning it back on prior to reading, decreases the maximum memory time to 30 seconds, two orders of magnitude greater than the calculated dielectric relaxation time of the material (.145sec). Memory times of greater than 20 minutes are realized when a constant external field (2000 volts) remains on the device.

The third factor, affecting the maximum storage time, is the energy density placed on the crystal by the write beam. The exact effect the energy density had was not known, therefore, the following procedure was used. Small amounts of write beam energy density, normally $5 uJ/cm^2$ in a pulse width of 1/50 sec, were continuously pulsed onto the device. The time between pulses was 5 seconds. The read beam was continuously illuminating the device during the pulsing of the write beam. The resultant optical output (output through the EG&G 450 radiometer) was recorded, and is displayed in Fig. 3. This graph was then used as an aid in determining how the write beam energy density would affect the storage times. The analysis of the pulsed optical output follows.

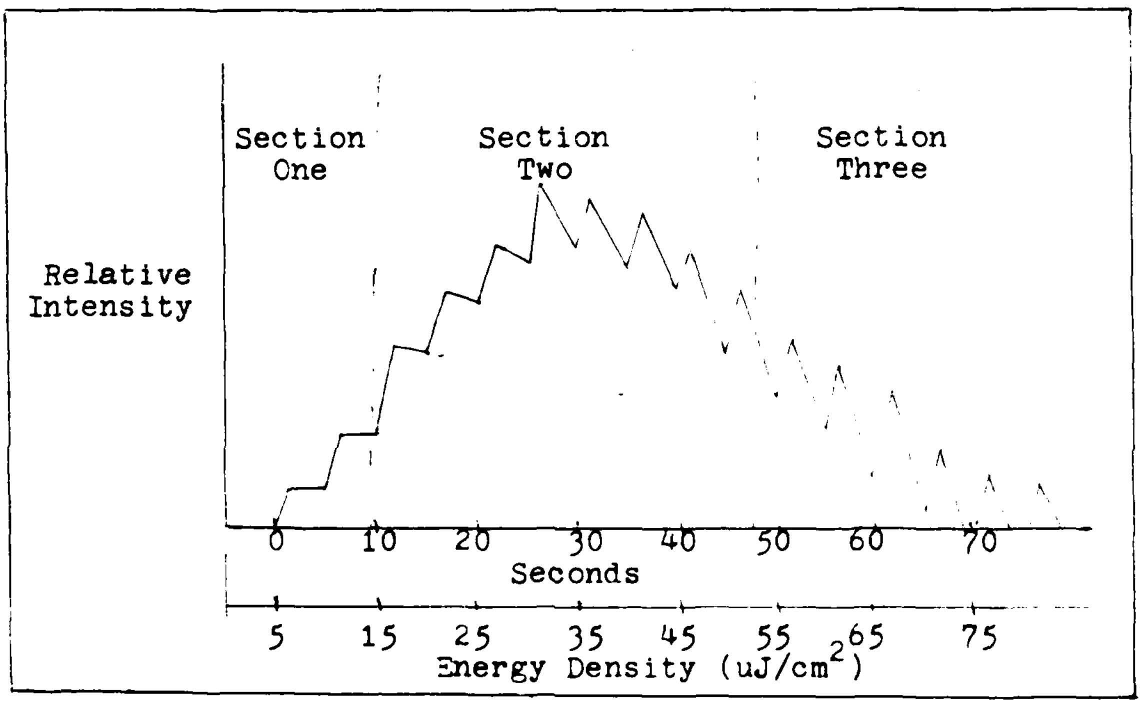


Fig. 3. Pulsed Optical Output

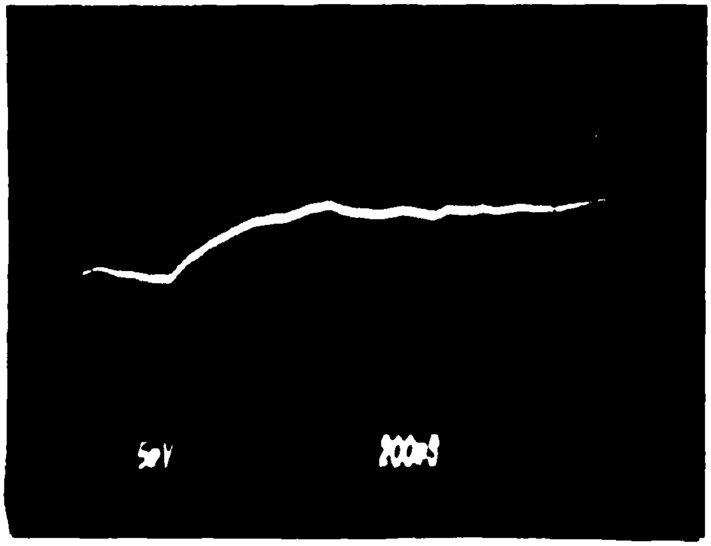


Fig. 4. Output From $5uJ/cm^2$ Input

As long as the total energy density placed on the crystal is below $10uJ/cm^2$, (Section one of Fig. 3), the output intensity continues to increase. That is to say that the visual output (output visually observed on a video monitor using a video camera for detection), or the radiometer output, will increase as each successive pulse is added to the device. Another important feature of this range of write energies is the length of time the optical output remains (Fig. 4). In some cases the output remained for more than two minutes. Recall this curve was obtained with the read beam continuously on the device. Therefore the length of time the device could store (retain the information without the read beam illuminating the device) is much longer since any erasure of the output caused by the read beam would be eliminated. In other words, the decay rate (rate at which the output intensity approaches the read beam only level with the read beam on) is directly related to the length of time (memory time) the device can store information.

It is necessary at this point to define a standard value for comparison of the optical output obtained at various memory times. The term "10%" memory time as used in this thesis will mean the length of time between writing and reading in which the optical output decays to a value that is 10% greater than the read beam only output, (note due to the detection system used the read beam level may not be "zero", but will be a constant value that can be used as a baseline for comparison). The 10% memory time of the output obtained in section one of the curve in Fig. 3 is only 5-10 minutes. This is due to the fact that the maximum intensity (brightness) of the output associated with this area of the curve is only 20-30% greater than the read beam only level. Therefore, decay to the read beam only level, even with the read beam off the device is accomplished in the 5-10 minute time frame.

The peak or middle section of the curve (section two of Fig. 3)

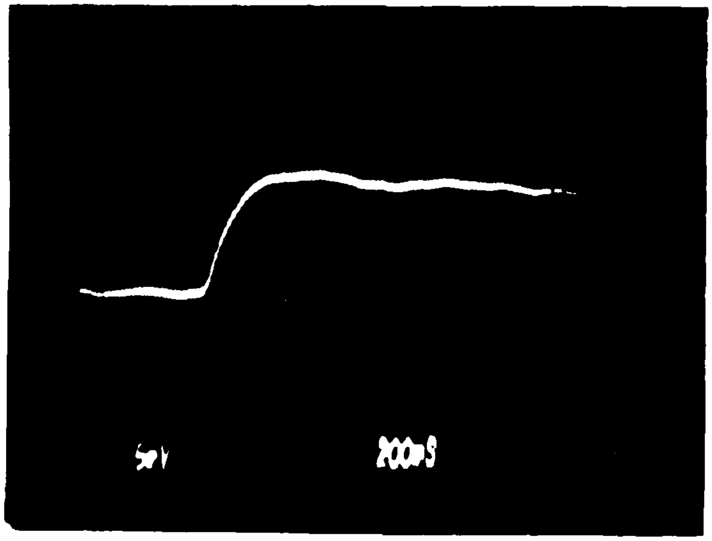


Fig. 5. Output From 25uJ/cm^2 Input

yields the maximum optical output. Note however, that in this section as write beam energy density is increased the decay rate of the optical output increases. In other words it takes less time for the output to decay from its maximum to the read beam only level than it did with write beam energy densities in the range of Section one of Fig. 3. A typical single pulse containing an energy density in this region would yield the output shown in Fig. 5 (read beam continuously on). This portion, section two, of the curve is contained between energy densities in the range of 10-50uJ/cm^2. The maximum "10%" memory time is produced by a write beam energy contained in section two of Fig. 3.

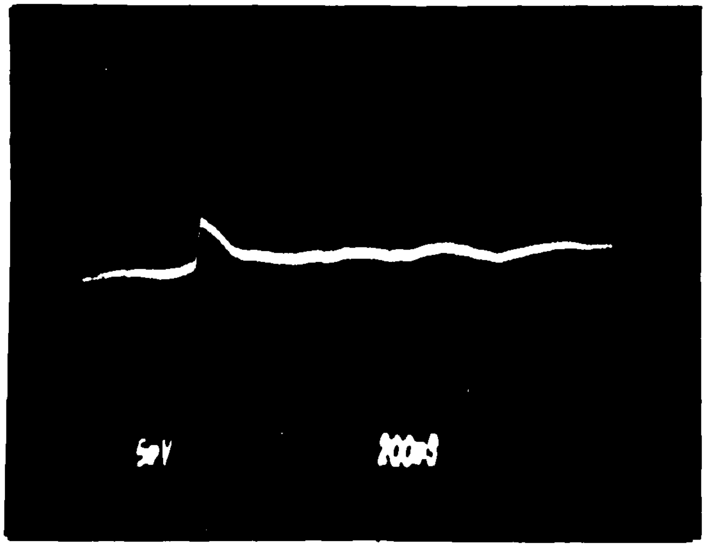


Fig. 6. Output From 150uJ/cm^2 Input

The final portion of the curve, section three, contains energy densities greater than 50uJ/cm^2. Note, in Fig. 3, the continual decrease in output intensity and the ever increasing decay rate as energy is added. The visual output (output viewed on the TV monitor) decays to a value below visibility in one second or less depending upon write beam energy densities which must be greater than 50uJ/cm^2. The rapidly decaying output leads to short memory times which is a desirable operating characteristic in the dynamic imaging mode of operation. Section three of Fig. 3 apparently corresponds to the "fairly high" energy region reported by the Soviets (14:169) in which the conducting PRIZ can operate in the dynamic image selection mode. A typical output of a write pulse containing an energy density greater than 50uJ/cm^2 is shown in Fig. 6.

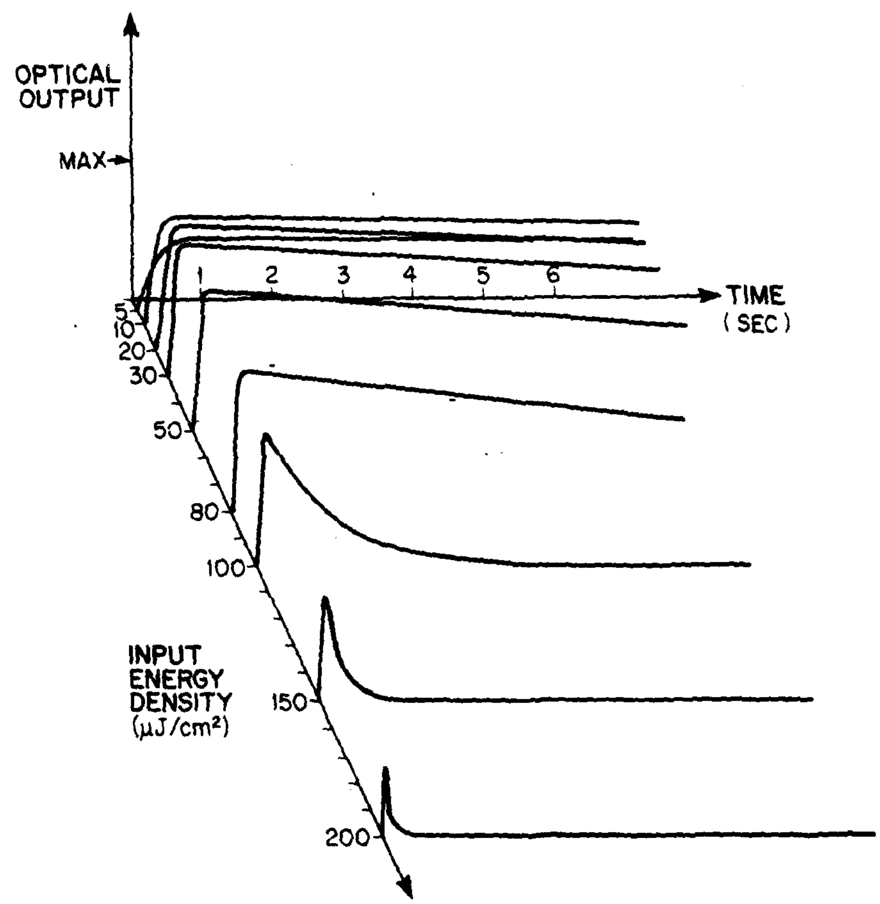


Fig. 7. Optical Output versus Time and Energy Density Input

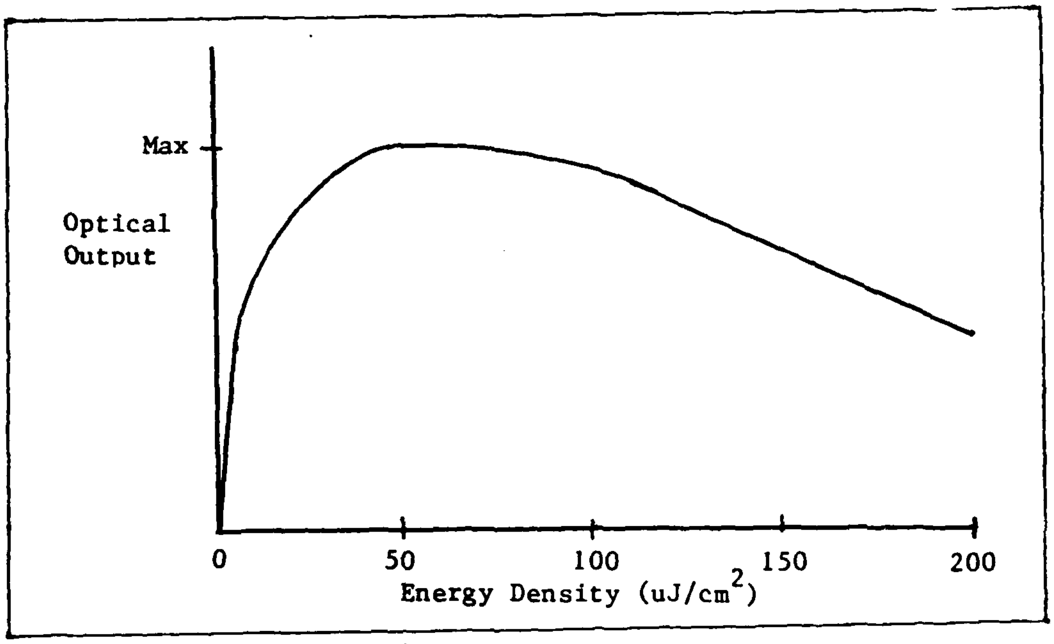


Fig. 8. Peak Output vs Input Energy Density

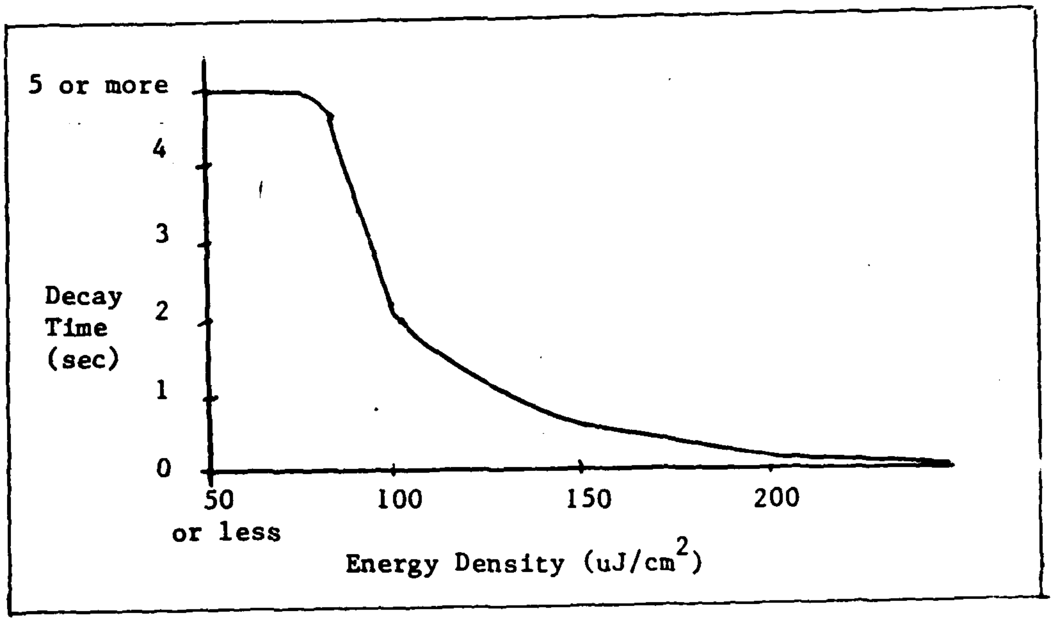


Fig. 9. Output Decay Time vs Input Energy Density

Figure 7 is a 3-D composite of optical output versus time and write beam energy density input. The graph displays the output obtained from a pulsed input of specific write beam energy density (read beam constantly on). Figure 7 represents a composite of Figures 4, 5, and 6.

Figure 8 is a plot of the peak optical output versus input energy density. It is a projection of the peak output points of Figure 7 onto the relative optical output/input energy density plane. As energy density is increased the output increases to a maximum then decreases. This is the same effect as increasing the voltage on a Pockels cell. The output will increase to a maximum at the halfwave voltage of the cell and then decrease. However, the Pockels cell will continue to produce this sinusoidal type of output as the voltage increases, whereas, the optical output of the PRIZ beyond the 200uJ/cm^2 point has not been closely studied. The data obtained for Figures 7 and 8 would lead one to believe that the optical output beyond 200uJ/cm^2 will only continue to decrease.

A plot of input energy density versus output decay time is displayed in Figure 9. At low energy densities (5uJ/cm^2) the decay time is relatively long (in excess of one minute with the read beam on). As the energy density is increased the decay time of the output decreases to a minimum measured decay time of 5msec at 200uJ/cm^2.

With the knowledge gained from Figures 8 and 9, Figure 7 becomes a powerful tool for describing device operation in light of specific applications. For instance, if one needs to know that an image was recorded, but does not need high contrast for image recognition, a low input energy density which yields long storage times could be used. If a medium storage time is required, and one must have high contrast, then an energy density near the peak of Figure 8 must be used. Finally if it is desired that the device be operated in the dynamic imaging mode, then energy densities above 50uJ/cm^2 should be used because of the higher output decay rates.

Specific Memory Results

There are two desirable conditions in obtaining a maximum "10%" memory time. The first condition would be to start with an output intensity that is much greater than the read beam only level. The second is to have a very slowly decaying output. Therefore, a compromising position between the extremely slow decay rates of section one(Fig. 3) and the high intensity outputs of section two (Fig. 3) was chosen. After analyzing the curve (Fig. 3) and applying the conditions required for a maximum "10%" memory time 15-20uJ/cm^2 was selected as the range of write beam energy densities to be used to evaluate device memory.

The write beam shutter and aperture were properly set to allow 15-20uJ/cm^2 onto the device with a single pulse input. The maximum length of time the conducting PRIZ can store data and produce any output greater than the read beam only level is one hour. The output at this time (according to the photometer) was only 3-5% greater than the read beam only level. However, visual observation (on the TV monitor) of the output image was not possible after one hour. The maximum "10%" memory time turned out to be 20 minutes. Visually the output was discernible, but very dim. The optimum memory time (maximum time between writing and reading in which the output is easily discernible and at least 40% greater than the read beam only level) was 10-15 minutes, depending on the exact amount of write beam energy placed on the device. Note for all memory time measurements the read beam was off the device until the predetermined time had elapsed. It is interesting to note that at the optimum memory time (as defined above) the output image remained visible (on the TV monitor) for an extremely long time even with the read beam on. At times the output image would remain on the video monitor in excess of one minute. This could be very useful if the device was used in an application where long storage times are required and several different operations need to be completed using the stored information.

V. Analysis of Results

The conducting PRIZ definitely displayed the ability to store information over a broad range of time. The device memory time (the length of time the device is able to store input data) is inversely proportional to the write beam energy density placed on the device. As the energy density on the device is increased the memory time decreases. Depending on the desired use of the device, memory times can be as short as milliseconds or as long as an hour. This allows the device to be operated as an intermediate term storage device, or as a real-time incoherent to coherent image transducer.

The actual application of the device will determine the write beam energy density required. For instance if a long memory time is desired, and the fidelity of the reproduced output is not important, low write beam energy densities (less than $10uJ/cm^2$) could be used. If on the other hand the device is to be operated in the dynamic imaging mode, write beam energy densities greater than $50uJ/cm^2$ must be used since they produce the rapidly decaying optical output required for dynamic image selection. The fact that the performance of the standard PRIZ device was dependent on the write beam energy was reported by Casasent (5:4220). The results contained in Chapter IV now allow one to make the same statement concerning the operation of the conducting PRIZ.

Additionally M. P. Petrov reported that the effect of dynamic selection manifests itself only at fairly high energies of recording (write) light (14:169). The results of this study not only verify, but also quantify this report. The write beam energy density must be greater than 50uJ/cm^2.

As previously mentioned it is difficult, and sometimes impossible, to determine what specific type of device, PROM, standard PRIZ, or conducting PRIZ the Soviets are discussing in their papers. However, the results presented by Shields (20:37-50) and in Chapter IV of this thesis clearly demonstrate the ability of the conducting PRIZ to perform as a storage device or as a dynamic image selector. Also all known Soviet references (14:169, 15:821, 17:250 for example) to the phenomenon of dynamic image selection mention either a modified version of the PRIZ or one with no dielectric layers. Therefore, it is logical to believe that dynamic image selection occurs specifically with the conducting version, in which case, if Casasent did actually experiment with dynamic image selection (5:4220, 6:3851), at least one of the devices tested at Carnegie-Mellon was a conducting version, or contained leaky dielectric layers.

Theoretical Analysis

The various operational conditions of the conducting PRIZ are dependent on the decay rate of the output signal. A slow decaying output is required for maximum storage, while a rapidly decaying output is required for dynamic image selection where multiple high velocity targets are to be detected. The decay rate of the output signal is directly related to the time it takes for the internal transverse field to reach zero.

A theoretical analysis of the effect of the space integrated transverse electric field on dynamic image selection is presented by Bryksin et.al. (1:193). In their analysis they present a model that yields an explanation of the process by which the net internal field approaches zero. An indepth study and further modification of their model is required to fully understand the dynamic imaging process.

A simplified explanation as to how the internal field relates to the decay time is through the recombination of "free" electrons with ionized (positive) donor sites. Complete recombination will yield an actual point by point internal field of zero. Since the decay time of the output is related to the rate the internal transverse field decays, the output decay time will also be related to the recombination time.

Starting from Golden Rule #2 (there must be an empty state for recombination to take place), (19:285) the recombination rate may be shown to be directly proportional to the number of empty positively charged donor sites available. The number of these positive sites produced per period of time is a direct consequence of the photogeneration of the donor electrons, which in turn is directly proportional to the number of write beam photons incident upon the device (energy density of the write beam). Therefore, the total number of recombination events per time period is directly proportional to the energy density of the write beam. The recombination time, and equivalently the decay time of the output, are proportional to the time per recombination event. The time per recombination event is inversely proportional to the write beam energy density incident upon the device. The results obtained from this study strongly suggest that this simple mechanism may control the decay rate. As the energy density of the write beam increases and the recombination time decreases the output decay time decreases.

Or expressed mathematically:

$$(Pw/Aw)*Tl=a/Tr=b/Td$$

where Pw=write beam power

Aw=write beam area on device

Tl=input pulse width (sec)

Tr=recombination time

Td=decay time

a and b = proportionality constants

VI. Other Observed Effects

Two additional effects were observed during this study: Reintensification and an effect that will be called Background Glow. Reintensification has been previously reported (15:819), (6:3852), however, Background Glow has never before been reported. Background Glow is a general optical output generated by either the read or write beam.

Reintensification

Reintensification is the effect caused by the change in the localized internal field when the write beam pulse is removed from the device. An initial optical output is produced as the shutter is opened, and the write beam is placed on the device. However, under certain conditions, a second output, or a reintensification of the first output is created when the shutter closes and the write beam is removed. Casasent states, "whenever the write light changes (goes on or off), an output image of the input data appears and then decays with a time constant that is a function of the intensity of the write light" (6:3852), but he gives no restrictions on the experimental conditions required for this phenomena.

In order to observe this effect the irradiance must be of such a value that the optical output will decay to a level near the read beam only level prior to shutter closure or the reintensified output will be lost in the original image. For shutter pulses which are 1sec or shorter, the energy density required must be in the range of Section Three Figure 3.

To verify the effect of reintensification an input pulse width of 0.6sec was used. The aperture was opened to allow a write beam energy density onto the device that would create a total output pulse width much less than the 0.6sec input pulse width. The results of this test are shown in Fig. 10. Figure 10a is a reproduction of the shutter pulse, while Figure 10b is the optical output recorded from the photodetector onto the storage oscilloscope. Reintensification of the output is clearly evident even though the decay time for the EG&G 450 photodetector used to obtain Figure 10b is relatively long (.15sec).

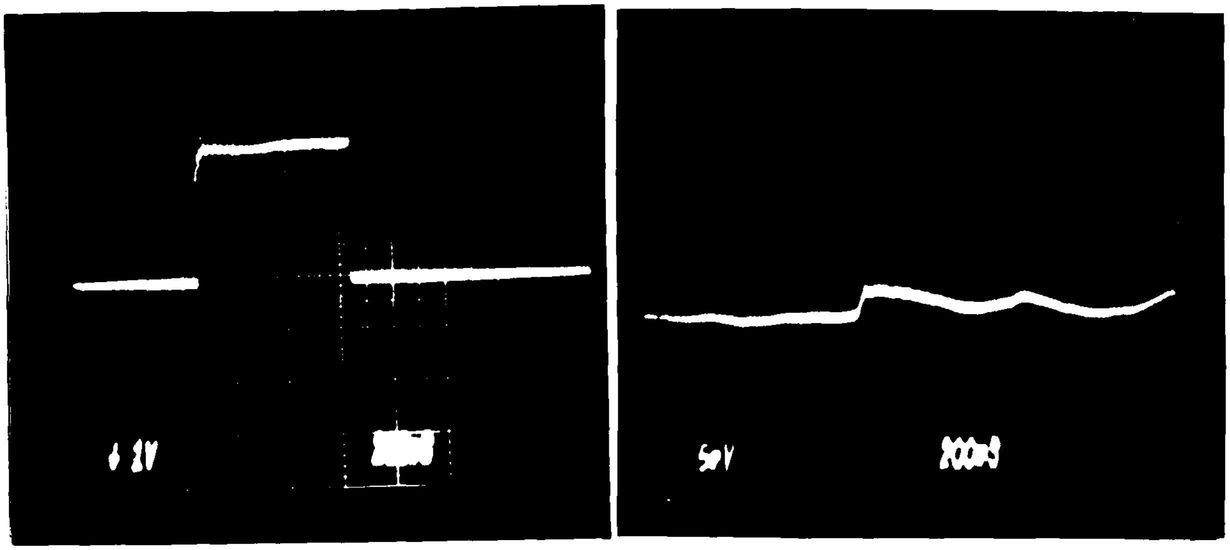


Fig. 10a. Shutter Pulse Fig. 10b. Output Pulses

Fig. 10. Reintensification

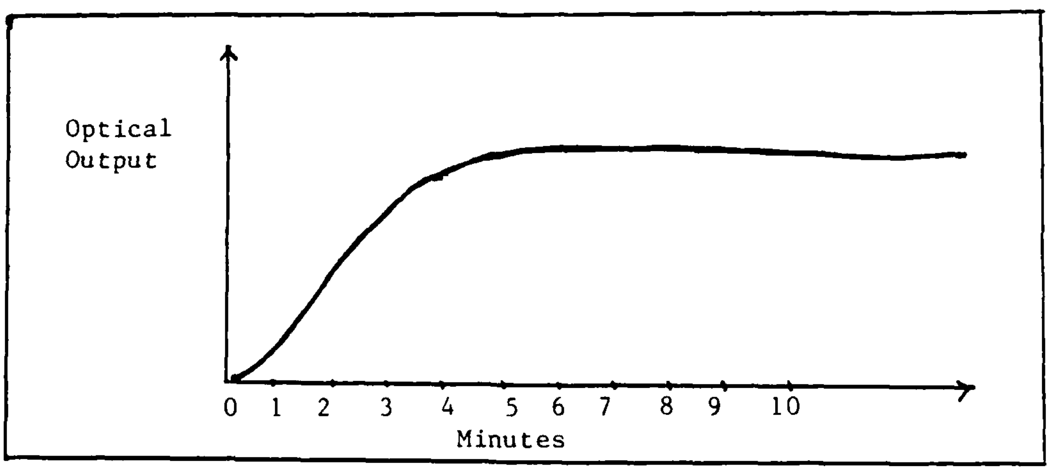


Fig. 11. Read Beam Only Output

Background Glow

Background Glow is a random optical output caused by either the read or write beam. The intensity of the glow varies across the crystal. For instance the read beam alone causes a slowly rising net optical output (Fig. 11). The total time for the read beam only output to reach a saturation is between 3 and 4 minutes. Viewing this effect on the video monitor reveals several "glowing" areas. These areas do not appear to be related in size, position, or intensity.

The glow caused by the write beam is different than that caused by the read beam. The write beam glow appears to be more localized, not as spread out, and of much greater localized intensity than that caused by the read beam. In fact, visually, the write beam glow appears more as localized "hot spots" than as a general overall glow. The intensity of the hot spots can appear on the monitor to be as high as that produced by the original write beam output, however, their location is adjacent to the original output image.

It appears that the Background Glow is a result of an accumulation of "trapped" charge carriers at gross crystal defects as they drift or diffuse through the crystal. Trapping of the charge carriers prevents recombination from occuring and causes a net internal field thus allowing an output to be observed. It is believed that the trapping may be caused by defects deep in the crystal band structure since moving the optical input has little or no effect on the position or intensity of the hot spots or glow areas. If this is in fact the case, the "hot spot" glow may provide a method of detecting crystal defects. However, this is only a hypothesis which requires verification.

VII. Summary Conclusion and Recommendations for Further Research

Summary

A quantitative analysis of the storage capabilities of the conducting PRIZ are presented in this paper. Included in this analysis is the relationship of write beam energy density with the storage time of the device. This is the first time that quantitative information concerning this relationship has been reported.

In order to obtain the quantitative information concerning device memory a thorough analysis of the optical output was made. There are three major factors; read beam operation, externally applied electric field, and write beam energy density, that affect the optical output of the device. All are discussed in this report along with a quantitative comparison of the optical output with various write beam energy density ranges.

Included in Chapter V is a discussion on the decay rate as a function of the input energy density of the write beam. The theory infers that the recombination time of the "free" donor electrons with the positively charge donor sites is proportional to the decay time of the optical output. However, it is shown that the recombination time is inversely proportional to the energy density of the write beam. The experimental results strongly agree with this theory, however it is recommended that an indepth theoretical analysis of the operation of the device be made.

Reintensification, an effect reported by the Soviets (15:819), was encountered during this research, and a section concerning this phenomenon is included. Additionally, Background Glow, a second effect encountered during this study is reported for the first time in this thesis.

Conclusion

The effort of this study was specifically directed at the storage capabilities of the conducting PRIZ. However, the data obtained during this research not only is useful in detailing the characteristics of the conducting PRIZ as a memory device, but also quantifies the operation of the device in the dynamic imaging mode of operation.

As an example, if 15uW of appropriate wavelength power is imaged onto the device in the form of a 0.5mm wide by 6mm high line the total power density on the device for a stationary input image would be $500uW/cm^2$. The output of this image would be a rapidly decaying pulse. It would be seen on the TV monitor as a flash (if it could be detected at all). If the same image line is now moved across the device with velocities varying from 1-40mm/sec the effective energy densities on the device would range from 250-6.25uJ/cm^2. This range of energy densities is in the operating range of the device (i.e. an output can be observed on the video monitor). The rate of movement of the input image across the device that will produce a high intensity output (note the energy density required to produce a high intensity output is in the range 25-35uJ/cm^2) for the described input image is in the range 10-7mm/sec. This is exactly the findings of Casasent on tests performed on Soviet devices: "The response of the device to an 0.5mm wide input line was measured for different velocities (1-40mm/sec) of the input object across the input plane, and it was found (13:165) that the response of the device peaked when the velocity was approximately 7mm/sec (6:3851).

The above example not only demonstrates how the information gained during this study can be used to explain the dynamic imaging mode of operation, but also verifies the fact that the device used has essentially the same characteristics as the Soviet device. It also explains why the Soviet's reported a maximum output at that specific input velocity. As shown in the example above it is ultimately the write beam energy density on the conducting PRIZ that determines the output, whether operating as a storage device or as a dynamic image selector. The specific write beam energy densities required for any desired operation (as a memory device or a dynamic image selector) of the conducting PRIZ have been presented for the first time in this thesis.

Recommendations for Further Research

A theoretical model explaining the operational characteristics of the conducting PRIZ is needed. Bryksin et.al. have developed a model of the dynamic imaging aspect. This model could be used as a starting point, and along with the information gained from this thesis, a refined model could be constructed. The three-dimensional characteristics of the internal fields generated by the photorefractive effect and a charge transport model that reflects the operation of the device needs to be reformulated in light of the results presented in this thesis. Such a model would be valuable in predicting device performance.

Analysis of the device's ability to reproduce an image while operating in the dynamic image selection mode would yield information regarding the PRIZ's application as a moving target indicator. A way to begin such an analysis would be using a 35 mm photograph negative as a background scene. Properly placed in the write beam path, the negative could be imaged onto the device. A second negative could then be used as a moving "target". The target could be moved across the background field at various rates, and the output recorded and analyzed. Circular polarization of the read beam should be used to eliminate the directional filtering characteristics of the device, and allow for a more faithful reproduction of the input target image. The analysis should include such information as: write beam energy density, target speed, target size, target shape, clarity of the output image, and the minimum time between detection of successive targets. This analysis would provide information which could lead to an eventual moving target indicator design using the conducting PRIZ.

Finally the ability of the device to operate as a real-time image processor should be investigated. Operating in this mode, the data to be imaged, and the operating speed should be in conformance with television standards (number of resolvable elements 10^5-10^6 with frame change frequency 20-30Hz). The device would normally be operated in a write/read/erase cycle to perform as an image processor. Therefore, the minimum write/read/erase times should be obtained. Additionally, the output resolution should be analyzed at these speeds. A second thought would be the ability of the device to operate in a write/read/self-erase cycle. This type of operation may produce even faster operating speeds, however, the high write beam energy density required for self-erasure may have detrimental effects on subsequent data. Analysis of the device as a real-time image processor may lead to the practical realization of a real-time optical data processing system.

Appendix: Device Fabrication

Fabrication of the devices used for this study was accomplished using the technique developed by Shields (20:36, 62-64). This procedure was duplicated and, to date, is the only known way to fabricate operational devices in the United States.

There were two devices made for this research. Both devices were fabricated in an identical manner, however, the BSO crystals used were not procured from the same supplier. This would insure that the fabrication technique, and not the specific base material, was responsible for the successful operation of the device. The qualitative tests that followed construction of the devices demonstrated nearly identical operational characteristics.

The first phase of the fabrication of the device is the evaporation of the chromium electrodes onto the BSO crystal. The first device used a crystal of (111) cut supplied by Crystal Technology of Palo Alto, California. The second device used a crystal supplied by Sumitomo Electric of Tokyo, Japan. The crystal to be plated was placed into the evaporation chamber along with a pellet of 99.9% pure chromium,

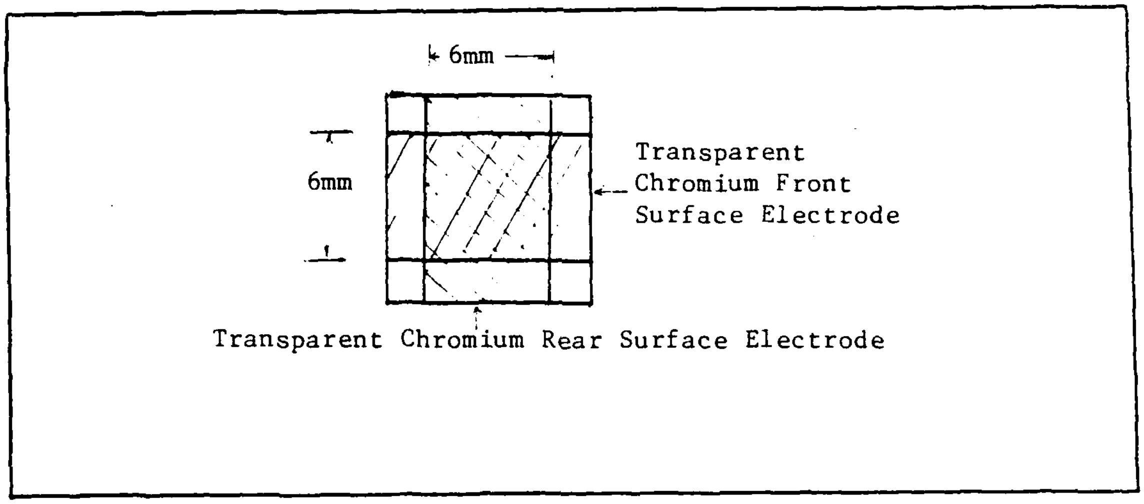


Fig. 12. Chromium Deposition Pattern

and the chamber was brought down to $2x10^{-6}$ torr (for chamber information see Shields (20:63). The chromium pellet was then brought to a temperature high enough to cause evaporation. Evaporation of the chromium onto the crystal continued for 60 seconds. This produced a 6mm wide chromium electrode on one side of the crystal. The crystal was rotated 90 degrees and turned over to allow for plating of the opposite side electrode. The above procedure was then accomplished on side two of the crystal. The crossed pattern produced by this procedure is shown in Figure 12. This pattern allows for a large active area yet helps prevent arcing from occuring. The second crystal was plated using the exact same technique.

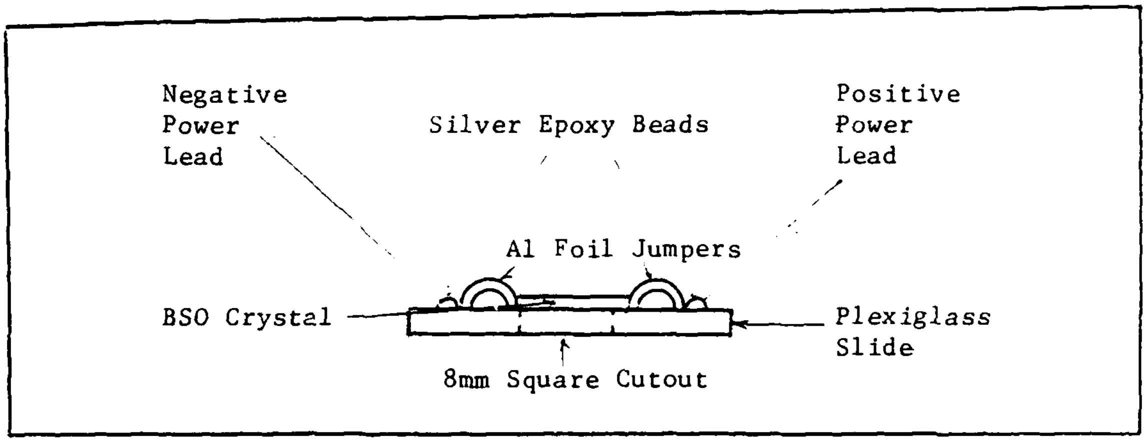


Fig. 13 Mounted PRIZ Device

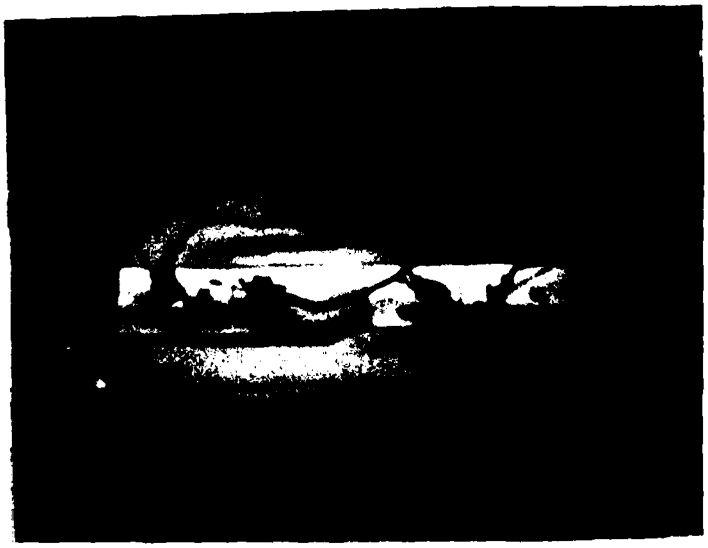


Fig. 14. Actual PRIZ Devices

Mounting the plated crystal was the final phase. A plexiglass slide with an 8mm x 8mm cutout in the center was used as the base for mounting. Silver paint was used to attach a strip of aluminum foil to each electrode, and also to attach the crystal to the plexiglass slide. The aluminum foil was then attached to the voltage supply leads and the plexiglass slide simultaneously using silver filled epoxy (Fig. 13). Figure 14 is a photograph of the actual devices. Once mounting was complete each device was separately placed into the experimental setup and tested for optical output.

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The memory (storage) capabilities of a conducting PRIZ spatial light modulator were quantified. Analysis shows a relationship between the storage capabilities of the device and operation of the device as a dynamic image selector. Conditions for optimizing these capabilities are established. This is the first time quantified values have been presented concerning either the storage or dynamic imaging capabilities.

The AFIT PRIZ's exhibited memory capability for up to one hour. The operating conditions that affect the device's ability to store information are: read beam on/off status, external electric field on/off status, and write beam energy density.

Two other effects were observed and reported. One is an effect referred to as background glow. This is the first report of the glow. The second is reintensification of the output image.

Construction of operational American devices exhibiting dynamic image selection was accomplished for only the second time. Fabrication of these devices was accomplished using the technique developed by Shields in his construction of the first non-Soviet PRIZ device exhibiting dynamic image selection.

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